Boundary Layer Transition Flight Experiment Overview

Brian Anderson, *Johnson Space Center*
Charles Campbell, *Johnson Space Center*

A thermal protection system (TPS) is required for the safety and success of any vehicle entering a planetary atmosphere, and such a system significantly affects the vehicle's design and ultimate weight. One of the design drivers to TPS sizing is the time during entry at which the boundary layer transitions from laminar to turbulent flow. The study of boundary layer transition (BLT) has been a significant effort for many decades, but the specific physics-based mechanisms that cause hypersonic BLT are poorly understood.

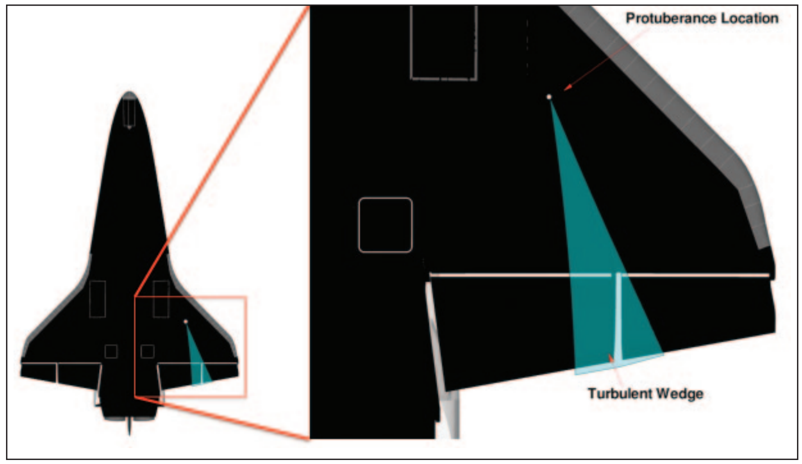

Fig. 1. *Selected protuberance location and predicted turbulent wedge.*

This lack of understanding hinders designers from accurately predicting when the boundary layer will become turbulent, and affects sizing and understanding of TPS robustness. If engineers know the geometry of a vehicle, they can obtain ground-test data from wind tunnels to develop engineering correlations.

However, one major weakness of a ground-based correlation approach is poor understanding of differences between wind tunnel and flight environments, and how those differences affect BLT. In addition to difficulties present in predicting BLT onset, hypersonic turbulent heating predictions have also proven to be challenging in many cases. A small amount of data exists to verify turbulent heating prediction models at low Reynolds numbers and hypersonic conditions.

During space shuttle mission STS-114, astronauts performed an unprecedented spacewalk to remove two protruding gap fillers because mission directors determined that the risks associated with the uncertainties concerning early BLT and resultant heating effects were higher than the risks of the spacewalk itself.

To mitigate these risks for future missions, the BLT team proposed a flight test using a protuberance on the orbiter to purposefully trip the boundary layer at a targeted Mach number. A protuberance tile and augmented instrumentation package (thermocouples) was installed on two space shuttle orbiters—*Discovery* and *Endeavour*.

The BLT flight experiment flew on five flights: STS-119, STS-128, STS-131, STS-133, and STS-134.

NASA Langley Research Center also led an activity, complementary to the BLT flight experiment, to image the orbiter during reentry using infrared detectors. The Hypersonic Thermodynamic Infrared Measurements team imaged the orbiter on each of the BLT flight experiment flights, as well as on STS-125 and STS-132.

Experiment Design Overview

Given the uncertainties in predicting BLT onset and associated TPS effects, and to ensure safety, the team decided early in the planning stages to approach the flight test program incrementally.

The team installed the protuberance on the port wing—outboard of, and downstream from, the main landing gear door (figure 1).

The flown height of the protuberance, derived using the orbiter BLT tool, was 0.64 cm (0.25 in.) for STS-119 and 0.89 cm (0.35 in.) for both STS-128 and STS-131. A height of 1.3 cm (0.5 in.) was flown for STS-133 and STS-134. These heights were designed to induce BLT at approximately Mach 15 (0.64-cm [0.25-in.] height), Mach 18 (0.89-cm [0.35-in.] height), and Mach 19 (1.3-cm [0.5-in.] height).

Fig. 2. Final protuberance shape, installed on tile.

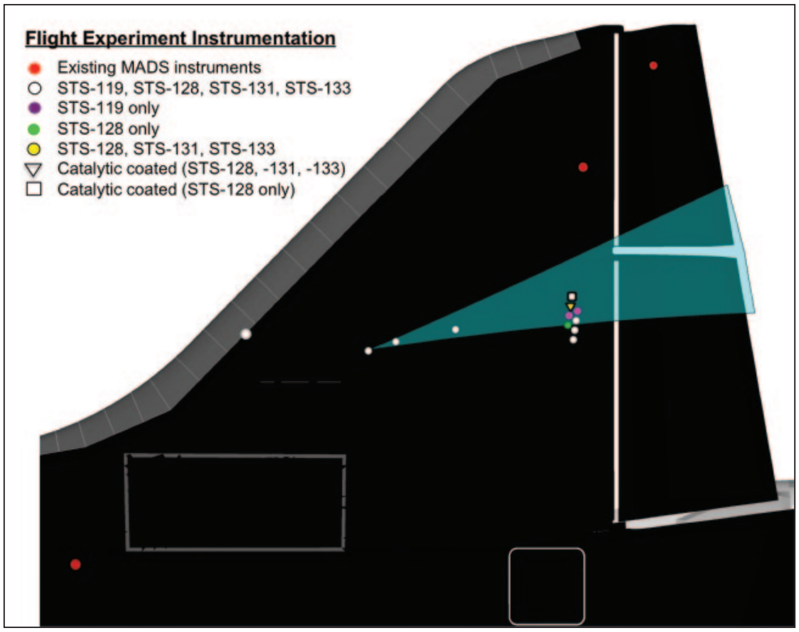

Fig. 3. *Instrumentation locations on* Discovery.

The protuberance tile was fabricated using Boeing Replacement Insulation-18 tile material; the installed length and width was 10-cm (4 in.) and approximately 1 cm (0.4 in.), respectively, for all five flights. The protuberance was machined into the tile such that the leading edge was oriented at a 45-degree angle relative to the predicted local flow streamline (figure 2).

The flight experiment instrumentation augmentation added 10 thermocouples on *Discovery* (figure 3) and four on *Endeavour*.

In addition to BLT and turbulent heating at high Mach numbers, another aerothermodynamic phenomenon not clearly understood is the potential coupling effect between turbulent flow and a catalytic material. Using expertise developed from previous flight experiments, a catalytic coating material originally formulated by NASA Ames Research Center was reconstituted and applied to study this potential effect.

Data from this aspect of the experiment could have significant impact on future capsule designs that use orbiter tiles. Technicians installed tiles downstream of the BLT protuberance with instrumentation directly below the catalytic coating for STS-128, STS-131 (figure 4), STS-133, and STS-134.

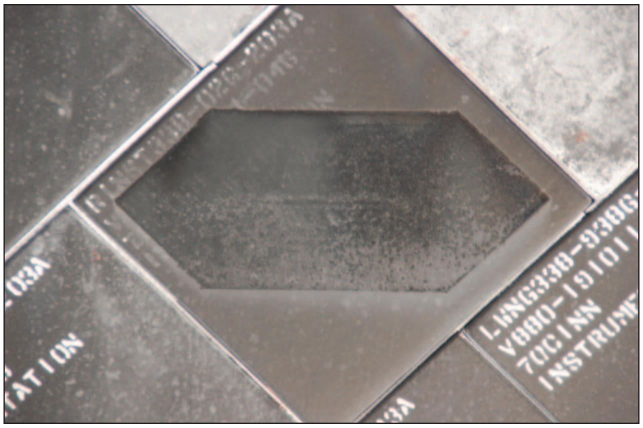

Fig. 4. *Post-flight runway photograph of catalytic coating following STS-131.*

Results and Summary

Data were obtained during reentry of STS-119, STS-128, STS-131, STS-133, and STS-134. Data from each flight thus far have proven to be useful; however, flight data from STS-128, STS-131, and STS-133 appear to be affected by an unknown temperature anomaly. At approximately 750 seconds into reentry during STS-131, instrumentation recorded a rapid drop in temperature (figure 5), which is not completely understood but seems to have been caused by environmental coupling with the orbiter instrumentation system, and initiated at roll reversal.

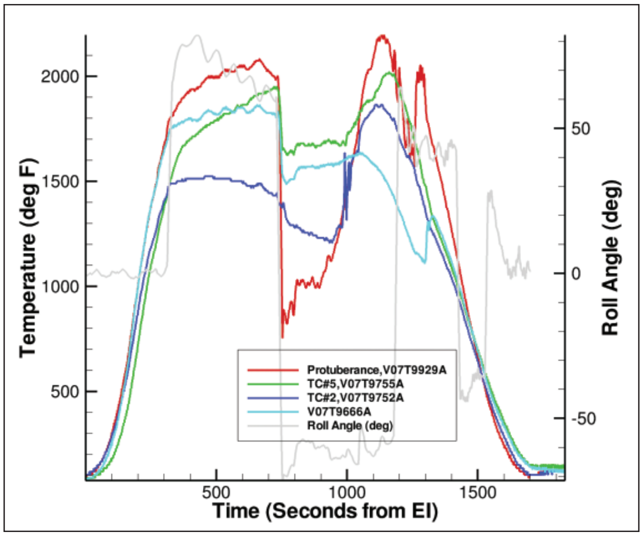

Fig. 5. *Representative thermocouple data from STS-131.*

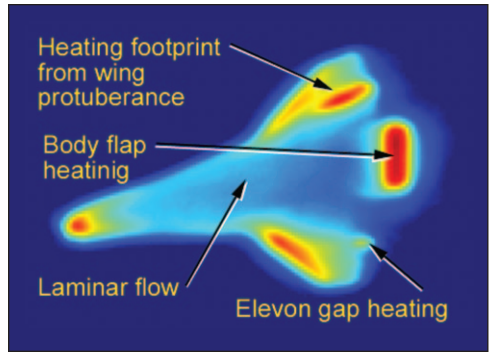

Fig. 6. *STS-128 Hypersonic Thermodynamic Infrared Measurement imagery showing the heating footprint caused by the protuberance.*

Unfortunately, this temperature anomaly has prevented significant conclusions for the catalytic coating tile experiment. The extent and magnitude of the heating footprint (figure 6) was inferred from the thermocouple data.

Conclusion

Data obtained during the flight experiment campaign have been beneficial to the technical community. Preliminary analysis indicates that the orbiter BLT tool is good at predicting BLT onset, with predictions typically within 0.5 Mach number of flight data indications. Analytical temperature predictions were much higher than the actual temperature data obtained from the flights, though analysts have not yet determined the cause for this discrepancy.

Future BLT tests will likely include experiments to determine the cause for this difference between predicted and actual flight temperatures.